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Semi-Annual Progress Report

Grant No. NAG-1-373

Reporting Period: July 1, 1983 - January 1, 1984

FLOWFIELD MEASUREMENTS IN A MODEL SCRAMJET COMBUSTOR USING LASER-INDUCED IODINE FLUORESCENCE

Submitted to:

National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23665

Attention: Dr. G. Burton Northam
HSAD, Mail Stop 168

Submitted by:

James C. McDaniel, Jr.
Assistant Professor

Report No. UVA/528228/MAE84/101
March 1984

SCHOOL OF ENGINEERING AND APPLIED SCIENCE

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

UNIVERSITY OF VIRGINIA
CHARLOTTESVILLE, VIRGINIA 22901

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1. INTRODUCTION

The objective of the research supported by NASA Grant NAG-1-373 is to obtain accurate, spatially-resolved measurements of flowfield variables, including pressure and velocity, in a model nonreacting scramjet combustor flowfield. The diagnostic technique to be employed is based on laser-induced fluorescence from iodine molecules seeded into the flowfield.

Proposal No. MAE-NASA-2603-83 outlined phase 1 of the research plan to be completed in the initial 12-month period of Grant NAG-1-373 (July 1, 1983 - June 30, 1984). The first 6 months of the grant period was to be devoted to modifying an existing wind tunnel facility at the University of Virginia to accommodate iodine seeding and to contain a specially-designed combustor test section, to complete the optical system setup, and to obtain preliminary measurements in an iodine static cell. The second 6 months proposed to obtain preliminary data from the scramjet flowfield in the form of flow visualizations and pointwise measurements using the iodine fluorescence technique. The progress made during the first six months of the grant period is reported herein.

2. LABORATORY RENOVATION

Upon arrival of the principal investigator at the University of Virginia in late June 1983, the proposed site for the research facility in the basement of the A&M Building (Room B001A) was examined, determined to be adequate for the research (as judged previously by Dr. Sam Fisher of U.Va. and Dr. G. Bert Northam of NASA/Langley) and the necessary formal approvals were obtained for securing the laboratory space for this purpose. The laboratory had been used for many years as the site of an electromagnetic-suspension wind tunnel facility and as of July 1, 1983 contained most of the apparatus required to operate this facility. The top photograph in Figure 1 is a photograph of the laboratory as viewed on July 1. A large liquid-helium-cooled dewar was suspended on cement-block pillars above an open pit in the center of the room. Large cables connected the dewar to power supplies located just outside the laboratory. Miscellaneous electronic equipment, hardware and an assortment of paperwork collected over the years of operation of the facility filled the room. Since the facility had not been used for several years everything was covered with a thick layer of dust. However, it was obvious that the necessary components for the proposed research were available in the lab: air supply, plenty of water and power for lasers and adequate space, completely enclosed and isolated from adjacent labs.

The first task was, therefore, the disassembly, removal and storage of the equipment from the electromagnetic-suspension wind tunnel.

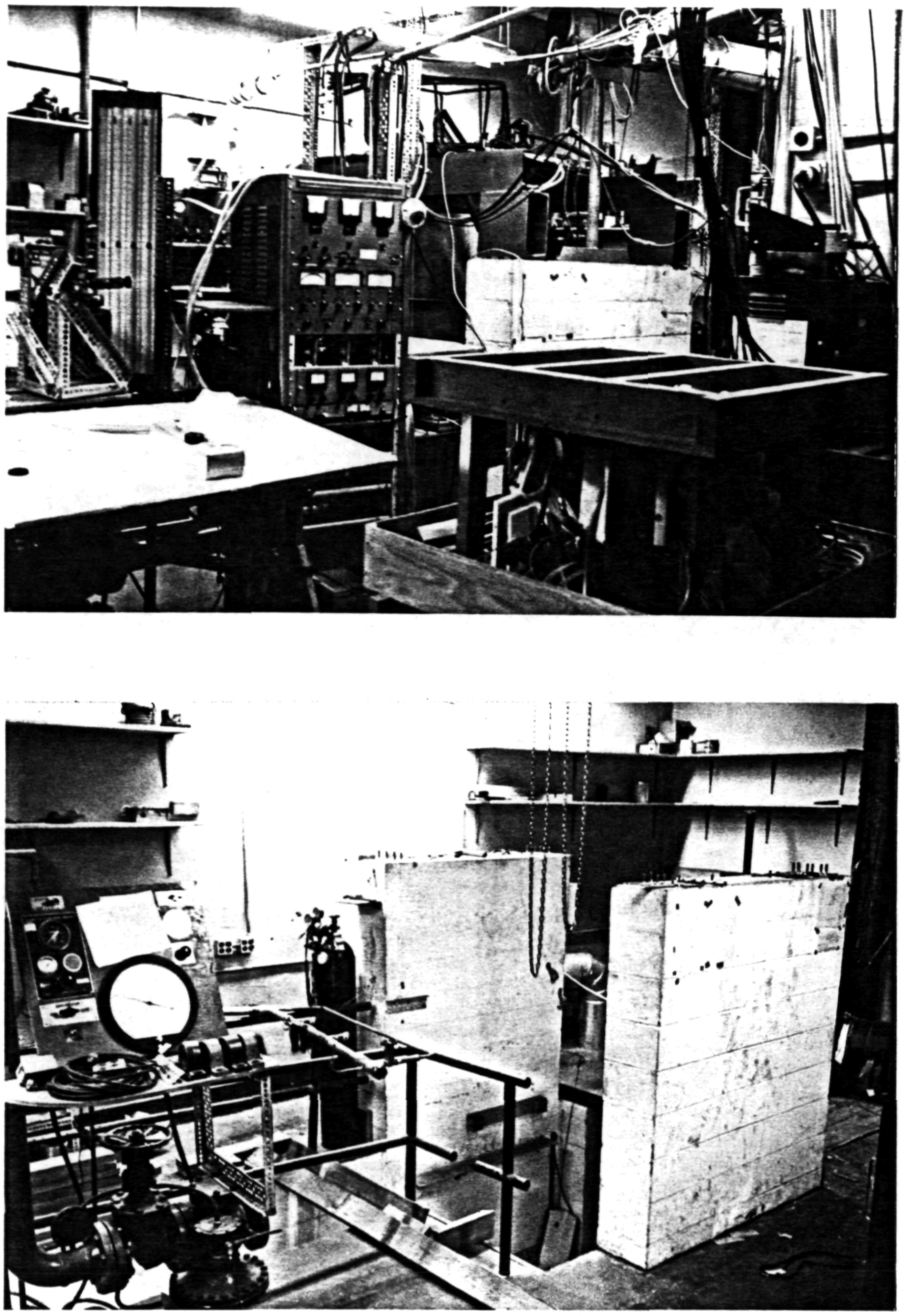

Figure 1. Photographs of laboratory before (top) and after (bottom) removal of electromagnetic-suspension wind tunnel facility and equipment.

Items identifiable as belonging to departments in the engineering school were returned, faculty members involved in the electromagnetic-suspension work removed and stored items purchased under old contracts, and remaining items were either retained for possible future use in the proposed research, stored or scrapped. The bottom photograph in Figure 1 shows the laboratory after removal of the old electromagnetic-suspension tunnel and equipment.

After clearing out the lab, the two cement-block supports were cut off and finished with concrete caps to support an optical table. Since these cement supports extend into the building foundation and are mechanically isolated from it by plywood spacers, they make ideal supports for an optical table.

With the laboratory stripped of old equipment and the cement supports shortened, the second task, renovation of the space for the future research, began. After repeated attempts to remove dust from the lab it was realized that a major problem had to be faced: the ceiling was covered with a thick layer of asbestos and dirt which showered down on the lab whenever someone walked on the floor above. This was not only a hazard to personnel working in the lab but completely unacceptable for a clean optical area. After consulting with the Environmental Health and Safety Department at U.Va. it was determined that the dirt could not be removed without removal of the asbestos and this would require approximately $10,000 and 6-12 months to complete. In order to solve the problem more reasonably it was proposed that a suspended ceiling be installed below the existing ceiling so as to completely entrap the dust and asbestos in an area to which access is

not needed. The suspended ceiling was installed by the Department of Physical Plant at U.Va. with the expense shared between the Office of the Dean and the Department of Mechanical and Aerospace Engineering. The top photograph in Figure 2 shows the lab in the process of renovation after installation of the suspended ceiling. The resulting space is not only very clean but much more adequately lighted than before. This photograph shows the optical table (still in shipping crate) mounted on the cement supports and a new raised wooden floor constructed over approximately one-half of the laboratory. The floor spans the pit area below and beside the optical table. Electrical power and water lines were installed under the floor to provide the optical table area with both 110V and 220V power and cooling water for lasers. A partition was constructed at the end of the raised floor area to support laser safety curtains (thereby, isolating the optical area from the remainder of the lab) and to provide railings around the steps leading to the pit area beneath the optical table. The bottom photograph in Figure 2 shows the laboratory after completion of the above-described renovation. This phase of the work extended well into the Fall due primarily to the delay caused by the unforeseen presence of asbestos on the ceiling.

Figure 2. Photographs of laboratory during (top) and at completion (bottom) of renovation phase.

3. MODIFICATION OF WIND-TUNNEL FACILITY

All sections of the previous wind tunnel downstream of the pressure regulator were removed as these sections were not useable in the new design. Figure 3 is a sketch of the overall iodine-seeded wind tunnel. The compressor, dryer, storage tanks and regulator remain from the old tunnel. The chamber for mixing iodine into the air, the new test section and the filter for removing the iodine before exhausting to the atmosphere will complete the new tunnel. This tunnel layout is essentially the same as Figure 5 of the original research proposal but without the pump downstream of the filter. The available Stokes 412 vacuum pumps at U.Va. were found to be incapable of running at the high pressure levels and throughput rates required without drastic modification. It was decided to simply exhaust the tunnel to the atmosphere and eliminate the pump in the initial operation of the tunnel. This raises the operating pressure in the test section at Mach 2 from approximately 150 torr to 290 torr (using a 3 atm reservoir pressure), causing a reduction in fluorescent signal level by a factor of about two. However, there should be ample fluorescence at this pressure level to permit quantitative measurements without using a large pump or fan to lower the back pressure.

A sketch of the charcoal filter which has been designed for removal of the iodine from the air stream is shown in Figure 4. The filter is made of a 55-gallon steel drum, with sealed lid, attached to the tunnel exhaust line and containing 130 pounds of Nuchar WV-H granular activated charcoal. A dead air space is provided above and below the

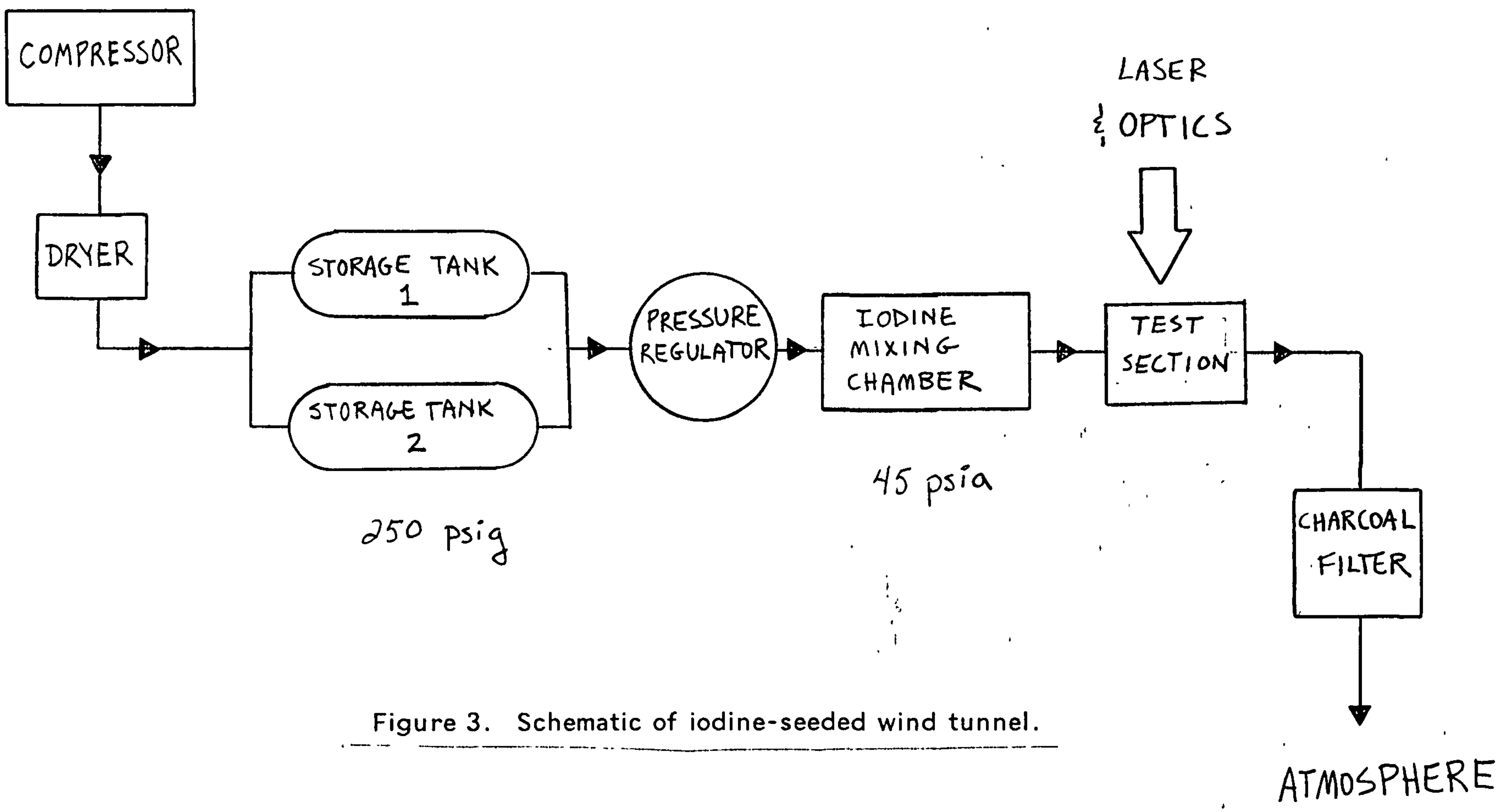

Figure 3. Schematic of iodine-seeded wind tunnel.

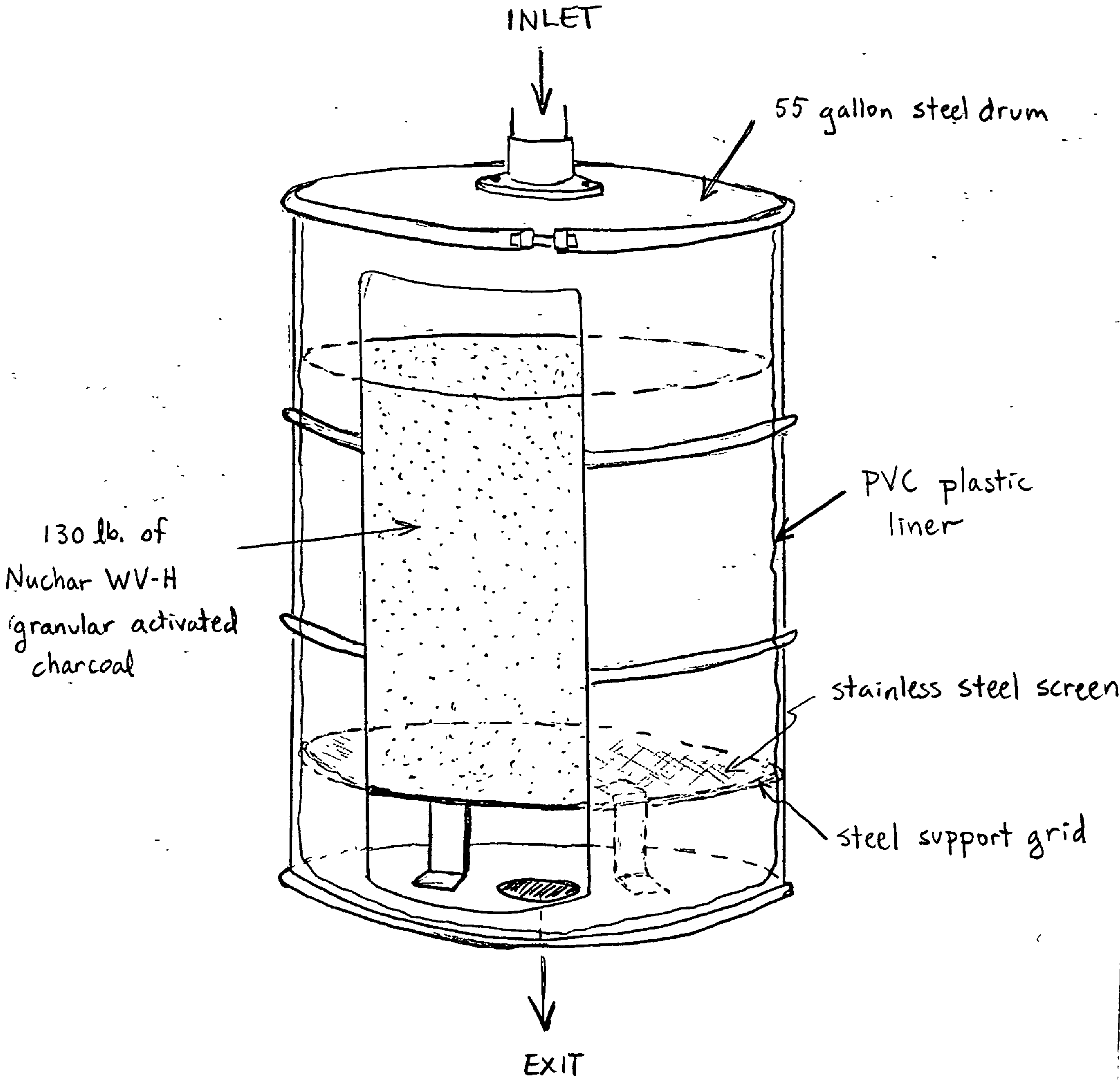

Figure 4. Sketch of Charcoal Filter.

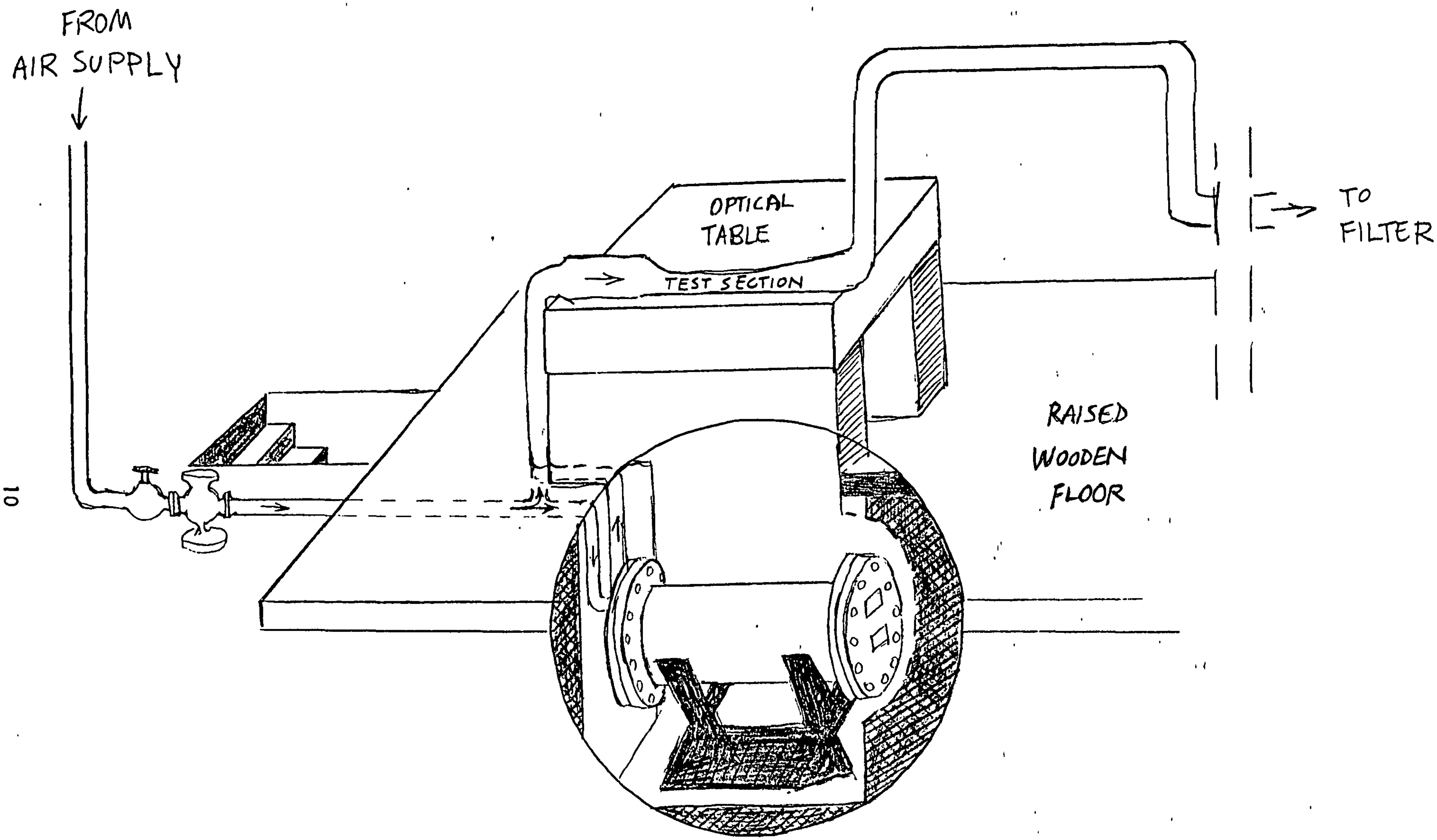

Figure 5. Cutaway sketch of laboratory showing iodine mixing chamber in pit area below optical table and wind tunnel test section suspended above optical table.

charcoal to force better utilization of the entire charcoal volume. A PVC plastic liner prevents direct contact of the drum with iodine. The design removes more than 99% of the iodine from the flow, allows 200-800 wind tunnel runs before the charcoal becomes saturated with iodine (at 5-20% pore loading by weight) and provides an internal filter velocity of 40 ft/min., in the desired range of 10-100 ft/min. for an optimized filter with minimum pressure drop. The charcoal can easily be replaced when it becomes saturated with iodine and will be disposed of by the Environmental Health and Safety Department at U.Va. All components for the filter have been received and are ready for assembly.

Preliminary designs for the iodine mixing chamber and the tunnel test section was completed in the Fall of 1983. The mixing chamber will consist of a large tank (approximately one-half cubic meter in volume) with interior manifolds to produce turbulent mixing over layers of iodine crystals. Access ports in one end of the chamber allow easy access for removal and replacement of the iodine crystals. The chamber will be located under the raised wooden floor below the optical table, as shown in Figure 5. The wind tunnel test section shown schematically in this figure will consist of a Laval nozzle producing Mach 2 flow for the scramjet combustor model, followed by a second throat and diffuser section. Extensive effort has gone into the design of both the mixing chamber and the test section in this reporting period but since the final designs were not complete as of January 1, 1984 these will be included in the next semi-annual progress report.

4. OPTICAL SETUP

As shown in the photograph of Figure 2 a Newport Research Corporation 5'x8' optical table was installed on the cement-block supporting pillars. This provides an ultra-stable platform for lasers and optical mounts.

The main piece of permanent equipment in the research budget was a Spectra-Physics Model 380A Scanning Single Frequency Ring Dye Laser. A demonstration-model laser (with full warranty) plus Spectra-Physics Model 404 laser power meter were purchased for a package price of $32,855 and have been delivered. Miscellaneous optical components (for example, an optical spectrum analyzer provided by the Office of the Dean) have been purchased and added to the optical system. A Lexel Model 95 argon laser, loaned to the research project by another research group in the Department of Mechanical and Aerospace Engineering (as mentioned in the original research proposal) was set up on the optical table to pump the ring dye laser. However, the output power of this argon laser proved to be inadequate to pump the dye laser significantly above its threshold level. It is, therefore, not adequate for the laser-induced fluorescence measurements with iodine. A larger argon laser with an output of at least 5 watts (all-lines) is needed and was searched for in labs known to the principal investigator around the country. The installation of the dye laser and subsequent completion of the required optical system depends upon and awaits the arrival of a suitable argon pump laser. The acquisition of a large argon pump laser is a priority item in the second six-month period of the research program.

5. STATIC-IODINE-CELL MEASUREMENTS

Measurements are needed in a static cell for the iodine transitions selected for excitation by the tunable dye laser in the scramjet combustor flowfield. These measurements were not initiated in the first semi-annual reporting period since the dye laser installation awaited a suitable argon pump laser. As soon as the lasers are operational these measurements will be completed before the first quantitative flowfield measurements are attempted.

6. PERSONNEL

Two Master-of-Science degree candidates have been involved in this research. Miss Linda Nicholson started on July 1, 1983 and worked full-time during the summer months under salary from the NASA grant. She continued her involvement through the Fall by enrolling in a 3-unit thesis research course while fully supported by a department fellowship. Her master's thesis will focus on quantitative pressure and velocity measurement using laser-induced iodine fluorescence.

A second student, Mr. John Graves, joined the project in September 1983. He also enrolled in a 3-unit thesis research course while being employed as a graduate teaching assistant in the department. His master's thesis topic is flowfield visualization in the model scramjet combustor using laser-induced iodine fluorescence.

Extensive use has been made of laboratory technicians during the initial stages of setting up the new laboratory. Mr. Curtis Wood, chief laboratory technician, was employed essentially full-time during the summer and part-time during the Fall. His time and that of the other technicians utilized was provided by the department without charge to the research contract.

7. PUBLICATIONS

A paper entitled "Nonintrusive Pressure Measurement with Laser-Induced Iodine Fluorescence" has been written by the principal investigator and accepted for publication in the Thermophysics Volume of the AIAA Progress Series by the volume editor. This paper was motivated by a desire to measure pressure in the scramjet combustor and discusses how this can be done using laser-induced fluorescence from iodine. The support of NASA Grant NAG-1-373 is acknowledged in this paper.

8. CONCLUSIONS

The initial six-month phase of the work has concentrated on renovation of the laboratory, preliminary designs for modifications to the wind tunnel facility, and preliminary assembly of the optical components. No initial static iodine cell measurements were accomplished, as originally planned within the first 6 months. Unanticipated delays were encountered due to the asbestos ceiling problem and the low output power of the available argon laser.

During the second half of the first year of the research program the optical setup will be completed, the new tunnel design and assembly will be completed and tunnel running conditions will be verified. Measurements will be made in a static iodine cell to verify the fluorescence behavior for the iodine transitions to be utilized in the flowfield. Preliminary flowfield visualizations will be acquired to characterize to overall behavior of the scramjet combustor flowfield over a range of step heights and transverse sonic jet configurations.

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School of Engineering and Applied Science

The University of Virginia's School of Engineering and Applied Science has an undergraduate enrollment of approximately 1,500 students with a graduate enrollment of approximately 500 There are 125 faculty members, a majority of whom conduct research in addition to teaching

Research is a vital part of the educational program and interests parallel academic specialties These range from the classical engineering disciplines of Chemical, Civil, Electrical, and Mechanical and Aerospace to newer, more specialized fields of Biomedical Engineering, Systems Engineering, Materials Science, Nuclear Engineering and Engineering Physics, Applied Mathematics and Computer Science Within these disciplines there are well equipped laboratories for conducting highly specialized research All departments offer the doctorate; Biomedical and Materials Science grant only graduate degrees In addition, courses in the humanities are offered within the School

The University of Virginia (which includes approximately 1,500 full-time faculty and a total full-time student enrollment of about 16,000), also offers professional degrees under the schools of Architecture, Law, Medicine, Nursing, Commerce, Business Administration, and Education In addition, the College of Arts and Sciences houses departments of Mathematics, Physics, Chemistry and others relevant to the engineering research program The School of Engineering and Applied Science is an integral part of this University community which provides opportunities for interdisciplinary work in pursuit of the basic goals of education, research, and public service